

Impact of Bridge Deck Cracking on Durability

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This paper gives the purpose and background of a current Iowa Department of Transportation (IDOT) research project entitled "Impact of Bridge Deck Cracking on Durability." Within this report, information is developed about the history of bridge deck deterioration and the use of epoxy coated rebars. Also, the procedures used to determine the impact of deck cracking on the condition of bridge structures evaluated in this project are described. Since the project has not yet been completed, conclusions and generalizations drawn from the research are only preliminary. Initial observations of the first 20 bridges evaluated have shown that the conditions of epoxy coated rebars at cracked locations can be much worse than those at uncracked locations. This can be attributed to the fact that deck cracking allows chlorides to penetrate the surface of epoxy coated rebars. Since many defects were found in the epoxy coatings of rebars in this study, this makes the reinforcing steel susceptible to corrosion and deterioration.

INTRODUCTION

Background

Concrete bridge components constructed with uncoated reinforcement and exposed to chloride salt solutions can suffer accelerated deterioration. These problems stem from the heavy use of de-icing chemicals (2.5 to 5.0 tons/lane/mile/year) on bridge decks in many States (1). Due to concrete's permeability and its natural tendency to crack, these de-icing chemicals can infiltrate the concrete and come into direct contact with the steel reinforcement, resulting in corrosion. Because steel expands 3 to 6 times its original volume when it corrodes, this can create areas of delaminations and spalls in the concrete (2). The delaminations and spalls further increase the corrosion rate of the steel by allowing even more chloride to penetrate the surface of the concrete. The problems can be so harmful to the structural capacity of the bridge that many decks required class A repairs (replacement of the upper portion of concrete and in some cases the top mat reinforcement) or class B repairs (replacement of the entire deck) after about 20 years of service.

In an effort to minimize corrosion of the reinforcement and the corresponding delaminations and spalls, the Iowa Department of Transportation (IDOT) and many other transportation departments

started using epoxy coated rebars in the top mat of reinforcing in the mid-1970's and in both mats in the mid 1980's. Although the performance of epoxy coated rebars in corrosive environments is superior to typical black steel rebars, large full depth cracks have caused some concern as to the condition of the reinforcement and epoxy coating in these areas.

In a study conducted by the Federal Highway Administration in 1996, the performance of epoxy coated rebars in bridge decks was evaluated in various states and in some parts of Canada (3). The study found that epoxy coated rebars were performing well, except in some circumstances. For example, the study determined that defects in the epoxy coating at cracked locations and other areas with high chloride concentration can result in corrosion of the reinforcement, which could cause major problems in the future. There was also some evidence that exposure to high chloride concentrations tended to make the epoxy coatings more brittle and weakened the bond between the epoxy and steel.

A study was conducted by the Iowa Quality Subcommittee on Structures which evaluated the condition of epoxy coated rebars at cracked locations. The study found that corrosion of epoxy coated rebars was occurring at cracked locations. Although the findings were important, they only represented the condition of the bridge decks at the time of the study, and further research on this area was recommended. In addition, since the IDOT's epoxy coating specification is different than the national standard, the performance of Iowa's bridge decks with epoxy coated rebars needed to be evaluated.

Research Objective

The ultimate objective of this research is to determine the impact of deck cracking on durability. The main objectives of this research, which started in April 1997 consist of conducting a literature review, visually inspecting several bridge decks, collecting and sampling test cores at several locations on bridge decks, determining the extent to which epoxy coated rebars deteriorate at cracked locations, and determining if beams deteriorate below cracked locations. The results will demonstrate the effect of deck cracking on durability. In addition, the results obtained from this research will be used as a guide for maintenance engineers to determine an optimal time to conduct preventative maintenance or overlay bridge decks to mitigate class A and B repairs.

The objectives of the research are to be accomplished in two phases. Phase I, which will be completed by August 1998, consists primarily of detailed field and laboratory studies to determine the extent of corrosion of epoxy coated rebars in various bridge decks across the State. Phase II will complement Phase I and will com-

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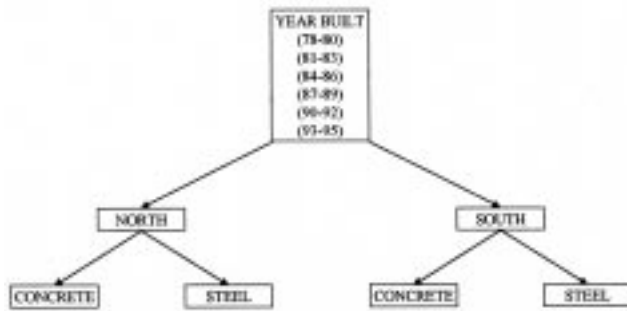


FIGURE 1 Bridge grouping.

plete the ultimate objective of this research, i.e., to evaluate and determine the impact of deck cracking on durability. Phase II is to consist of a more detailed analysis of a few bridges selected from those evaluated in Phase I.

BRIDGE SELECTION

At the time this project was initiated, the IDOT's bridge records indicated that there were 711 bridges built between 1978 and 1995 in Iowa with epoxy coated rebars in the top mat or both the top and bottom mats. In deciding which bridges to select for evaluation in this project, the characteristics of each of these bridges were obtained from the IDOT's database. The bridge records obtained included bridge type, bridge length and width, length of maximum span, number of spans, year built, ADT, ADTT, deck condition rating, superstructure condition rating, substructure condition rating, the location of ECR, and more.

The effects of many of the above listed conditions on the deck condition rating of each bridge were analyzed. The analyses showed that the deck condition rating was impacted most significantly by the age of the structure, the geographic location of the structure, the type of structure (concrete or steel), the ADT, and the ADTT. For this reason, the selection of bridges was grouped on the basis of age (1978 to 1980, 1981 to 1983, 1984 to 1986, 1987 to 1989, 1990 to 1992, or 1993 to 1995), geographic location (northern or southern Iowa), and type of structure (concrete or steel). This grouping scheme is shown in Figure 1. The average daily traffic was not included in the grouping process since this would have restricted the sample size of each group so much that many of the groups would be too small to be represented in the sampling process.

Since the long term durability of bridge decks with epoxy-coated rebars was the focus of this project, more older bridges were selected than newer bridges.

RESEARCH PROCEDURES

Field Evaluation

With the exception of a few bridges, four cores were taken from each bridge deck.

Two cores from each bridge were taken directly at crack locations, while the other two cores were taken from locations of the deck that showed no signs of cracking. The two "cracked" and the two "uncracked" cores were taken from different locations of the deck. One of the "cracked" cores and one of the "uncracked" cores were taken near the gutter line of the deck, while the other two were taken near the centerline of the deck. To simplify traffic control, all cores on each deck were taken from only one side of the bridge centerline, which was arbitrarily chosen.

Reinforcing bars in each bridge deck were first located using a pachometer. As often as possible, cores were taken at locations where longitudinal and transverse top mat rebars intersected. Cores were drilled from approximately 4 to 8 inch depths, and on several occasions bottom mat reinforcing bars were also drilled.

While the cores were being drilled, concrete powder samples at five locations across each bridge deck were collected. Two samples were obtained at each location. One sample at each location contained concrete powder drilled from a depth of 0.5 in. to 1.5 in. The other sample contained concrete powder drilled from a depth of 2.5 in. to 3.5 in.

Laboratory Evaluation

After the cores were drilled from the bridges, they were evaluated in detail. The condition and general properties of the cores and rebars were described by the procedures in the following sections.

Physical Properties

Classification of the physical properties of the cores consisted of various measurements and observations. Measurements were made on the concrete cover over reinforcing bars, the diameter of the rebars, the lengths of the rebars in the cores, the total depths of the extracted cores, the orientation of the rebars in the cores, and the orientation of cracks within the cores. In addition, factors such as the number of pieces that the core was broken into from the coring process, the number of rebars collected during coring, the type of rebar in each core, and whether or not a reinforcement tie was present were also noted.

Crack Dimensions

A microscope with variable magnification was used to determine the crack dimensions in cores taken from cracked locations of bridge decks. To obtain accurate measurements, samples were cut at ap-

TABLE 1 Rebar Rating Descriptions (4)

Rating	Description
0	No evidence of defects or corrosion.
1	One or more defects in the epoxy coating which don't show evidence of corrosion.
2	One or more defects in the epoxy coating which show some evidence of corrosion.
3	Corrosion area less than 20% of total ECR surface area.
4	Corrosion area between 20% to 60% of total ECR surface area.
5	Corrosion area greater than 60% of total ECR surface area.

proximately 90° to the crack orientations. These samples were then polished with various grades of sandpaper. This procedure made it possible to record distinct crack width measurements that weren't altered by the chipping off of concrete near cracks during coring.

To record the crack widths, the polished surfaces were placed under the microscope and digital pictures were taken through the microscope at 0.5 in. incremental depths along the cracks. These pictures were then inputted into a computer program which could calibrate the pictures and allow the user to measure crack widths on the computer screen. A total of three crack width measurements were taken at each incremental depth in each core taken from a cracked location.

Chloride Content

Three or four concrete powder samples of at least 20 grams were collected from each core at different depths. The powder samples were drilled horizontally with respect to the deck surface using 3/8 in. diameter drill bits. For each core, one powder sample was drilled at the mid-depth of the lowest top mat reinforcing bar. The second and third powder samples were drilled at the third points between the deck surface and the rebar. In cores which contained a bottom mat reinforcing bar, a fourth powder sample was drilled at the mid-depth of this rebar. An x-ray diffraction instrument was used to determine the total chloride content in each of the concrete powder samples.

Rebar Condition

An important part of the core evaluation involved describing and classifying the condition of the rebars within each core. Although many of the rebars were separated from the cores while being drilled from the bridge decks, most of the rebars were still embedded in the concrete cores and had to be broken out in order to be inspected. Each rebar was evaluated for several characteristics, including the amount of corrosion, number of defects in the epoxy coating, and the amount of discoloration of the coating.

Each rebar was given a rating from 0 to 5. The rebar rating was categorized as shown in Table 1. (Note: The corrosion percentage for each bar was based on the surface area of the small bar sample collected and does not represent the entire length of the rebar.)

TABLE 2 Coating Bond Rating Description (4)

Rating	Description
1	Well adhered coating that cannot be peeled or lifted from the substrate steel.
3	Coating that can be pried from the substrate steel in small pieces, but cannot be peeled off easily.
5	Coating that can be peeled from the substrate steel easily, without residue.

Epoxy Color

When field coring was initiated, it was noticed that many of the rebars had distinct areas where the epoxy coating was much darker than normal. In order to investigate if the discoloration had any impact on the effect of the epoxy coating, the darkest area of each rebar was compared to a color chart and given a rating which signified the color that matched the epoxy most closely.

Epoxy Coating Hardness

The epoxy coating hardness was tested in order to determine if there was any significant correlation between the epoxy hardness and other characteristics, such as chloride content, bridge age, corrosion, etc. The coating hardness of each rebar was tested using the Pencil Hardness Test described in NACE TM0174 - Section 6.1.5.

Epoxy Coating Bond

The knife adhesion test was used to determine the degree of bond between the epoxy coating and the steel on each rebar. The knife adhesion test was performed on the most discolored area of each extracted rebar. The knife adhesion test is described in NACE TM0185 - Section 5.3.2.1. The epoxy coating was rated according to Table 2.

Epoxy Thickness

The thickness of the epoxy coating was measured using two different techniques. A few samples were measured by encapsulating one end of the rebars in a plastic resin which hardened around the epoxy coated rebars. The ends of the rebars with the hardened resin were then sanded off to expose an unaltered epoxy cross section which could be read clearly under a microscope.

Other samples were measured while still intact inside the cores. The epoxy thickness measurements of these samples were taken with the microscope and digital camera while the crack width measurements were being taken. Since the cross sections of the samples were sanded while still encased within the cores, the rebar and ep-

oxy cross sections were relatively distinct, which allowed for accurate measurements.

The epoxy thickness measurements were not taken for all of the rebars in the study due to the variability of the epoxy thickness around most of the rebars. The epoxy thickness measurements ranged from about 0.05 mm (2.0 mils) to about 0.28 mm (11.0 mils). The thicknesses of the epoxy coatings around the ribbed areas of the rebars were, in general, much less than other areas. Since the thin areas of epoxy would probably have a large impact on the effectiveness of the coatings, measurements on just a few locations of each rebar may not be representative of the coating.

Scanning Electron Microscope

Four epoxy-coated rebars and a cross section from one core were analyzed under a scanning electron microscope (SEM). A number of different characteristics were measured with the SEM, including the chloride content at different locations in the concrete, epoxy coating thickness, and the various elements that made up the concrete, steel, and epoxy-coating. Additionally, the darkened areas seen on the epoxy of some of the rebars was closely examined for deterioration. These showed microscopic pattern cracking on the surface of the epoxy, which could possibly affect the corrosion protection offered by the epoxy coating.

PRELIMINARY FINDINGS

From the evaluation of cores from the first 20 bridges in the study, some preliminary observations were made. The following are for informational purposes only and may not reflect the final conclusions of this project.

One of the most interesting findings is that all of the rebars that were evaluated as having a rebar rating of 3, 4, or 5, i.e., bars which had surface corrosion undercutting the epoxy coating, came from cores that were taken through cracks. Of all the rebars taken from uncracked areas of the bridge decks, none had rebar ratings higher than 2.

The rebar ratings of 0, 1, and 2 represented relatively good rebar conditions, although the defects in the epoxy coatings of rebars rated 1 or 2 could lead to corrosion problems in the future. Thus, it

appeared that the presence of cracks in the deck surface had a large impact on the condition of the rebars below these cracks.

Although some of the bars obtained had significant corrosion on the steel surface, a large buildup of corrosion by-product was not seen. Also, no delaminations or spalls were evident on the decks where these rebars were cored.

These questions will be further addressed in Phase II of this project. Successful completion of this project will assist bridge engineers in making decisions on when to overlay bridge decks.

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REFERENCES

1. Krauss, P.D. and E.A. Rogalla. *Transverse Cracking in Newly Constructed Bridge Decks*. Report 380, National Cooperative Highway Research Program, 126 pp., 1996.
2. *Corrosion Detection in Reinforced Concrete Bridge Structures*. Demonstration Project No. 84, Federal Highway Administration, Washington DC., 1992.
3. Smith, J.L. and Y.P. Virmani. *Performance of Epoxy Coated Rebars in Bridge Decks*. FHWA-RD-96-092, Federal Highway Administration, McLean, Virginia, 104 pp., 1996.
4. *Verification of Effectiveness of Epoxy-Coated Rebars*. Project No. 94-05, Pennsylvania Department of Transportation, 1997.